Stability Analysis of Jointed Rock Slope by Limit Equilibrium and Strength Reduction Method – A Case Study

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Abstract. Analyzing the stability of rock slopes using empirical methods or by numerical modelling is of great challenge. Determining the design parameter for the analysis may not be much realistic to the field conditions. An attempt for calculating the factor of safety of the rock slope along the joint plane was put forward in this paper. Using the kinematic analysis, the critical joint sets were identified which were then analyzed using limit equilibrium method to find out the factor of safety with different combination of loading. Numerical modelling was used to study the behavior of slope during failure in a global scale. The effects of discontinuities have been incorporated in the rock mass by strength reduction method. A case study was performed over proposed dam abutments. The challenges in obtaining the representative design parameters, modelling of the rock slope, analyzing the slope behavior and designing the structural support systems are provided in this paper

Keywords: Kinematic Analysis, Limit Equilibrium, Strength Reduction Method, Structural Support System

1 Introduction

Various geological and geotechnical challenges confronted during the stability analysis of rock slope for dam abutments composed of jointed rock mass has been discussed in this paper. The whole study was divided into geological and geotechnical sections. The geological study mainly comprises of identification of basic geology of the field, rock structure, structural elements and its orientation etc. However Geotechnical study embraces kinematic analysis to identify the type of imminent slope failure, limit equilibrium analysis to find out the factor of safety of structural failures and numerical modeling of the slope to study the behavior of slope in global scale under various combinations of loads. Behavior of slope under critical combinations of load is identified and suitable treatment measures are suggested for stabilization of natural slope for safety and convenience of project construction stages.

2 Preliminary Field Survey

The analysis of rock slopes completely depends on the slope geology, structural features in rock, shear strength parameters of rock mass and geometry of the slope. Identification of naturally existing joint sets and their orientation in field is limited to apparent outcrops and has to be interpolated which is a challenging task and requires field experience. The depth and persistence of joints plays a significant role in determining the size of the wedge which again depends on basic assumptions. The categorization of rock mass based on different established classification systems and determining its properties from supporting correlation, showed much variation from that calculated from the lab test results. Hence, selection of representative strength parameters is also of great challenge and form basis of the analysis.

3 Slope Stability Analysis

3.1 Introduction

Rock slope stability analysis is carried out to identify the most vulnerable locations of rock slope which are prone to any type of shear failure under critical combinations of external loads and quantify its instability. Vulnerable locations are then stabilized by providing external support elements which contributes to the resisting forces by increasing the Shear strength of the failure plane.

3.2 Kinematic Analysis

The joint sets as obtained from the field are plotted in the stereographs, as shown in figure 1, along with slope face to identify the possibility of any structurally controlled failure i.e. planar or wedge failures. The angle of internal friction of the rock joints is also plotted in the stereograph to check the likelihood of slide. However, it’s quite challenging to conclude the failure of planar/wedge blocks suggested by kinematic analysis in line with the actual field conditions. The failure of rock planes/wedges in field is actually controlled by the weakest planes of contributing joint sets.

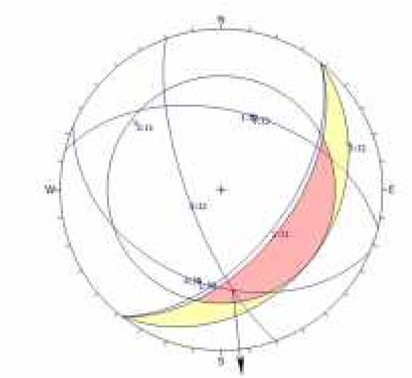

Fig. 1. Stereo plots showing the wedge formation

The stereo plot shown in Fig 1. represent the possibility of wedge failure between the joint sets J2 and J1. The plunge/failure direction is shown by an arrow. The area between the slope face and the fiction circle shown in red is considered as the most critical zone. Any intersection of joints falling in this region indicates the possibility of wedge failure.

3.3 Limit Equilibrium Approach

Limit equilibrium method is one of the traditional stability analysis method used to obtain the factor of safety of the potentially unstable slope at the verge of failure. The wedges which are prone to failure as identified from the kinematic analysis have been analyzed using limit equilibrium based software to obtain its FOS. Cohesion and friction angle of the contributing joints are critical parameters which governs stability of the wedge and hence considering the appropriate shear strength parameters is of great challenge.

The basic friction angle of the joints in the same type of rock varies based on surface roughness. Hence obtaining the characteristic shear strength parameters of the rock joints by conducting representative shear test is another challenge.

Swedge software of Rocscience is used to compute the factor of safety using Limit Equilibrium Method. Slope geometry such as height, dip amount and direction of slope face, orientation of critical sets of joints, shear strength parameter of slope materials are used as input in Swedge analysis. Minimum Factor of safety with different loading condition before and after providing support systems can be obtained.

3.4 Strength Reduction Method

In order to understand the behavior of the rock slopes, numerical techniques like Finite Element Method (FEM) have been adopted widely now days. Numerical modelling techniques are developed to provide approximate solutions to problems, which otherwise, would not have been possible to solve using conventional techniques.

The rock slopes with highly spaced joint sets are assumed as a continuum element. Representation of rock mass considering the effects of joints is also a challenge. Various assumptions such as homogenous and isotropic behavior of rock mass are a sort of solution to tackle the challenges of solving sophisticated stress calculations by reducing the size of constitutive matrix. Elastic modulus and Poisson's ratio are the basic elastic parameter that should be known while performing FEM analysis.

3.5 Rock slope stabilization measures

Slope Stabilization measures involve treatment of slope by strengthening of the strata itself or by installing some external structural elements either to prevent the failure or protect the elements from the failure. The rock support system includes Rock bolts, Shotcrete, wire mesh, cable anchors etc.

4 Case Study

A rock slope stabilization study has been carried out in Himalayan region for an upcoming Dam site of a hydro power project. Principle rock type exposed in the study area is quartzite and dolomitic limestone. Dolomitic limestone is present conformably over quartzite on the right bank as shown in figure 2.

The rock mass encountered consists of closely spaced joints along with other geological structures like shear zones and folds. The formation and possibility of sliding of unstable wedge were identified by the kinematic analysis. The identified unstable wedges were further analyzed by limit equilibrium method for find out the critical factor of safety under various conditions of loading. Global stability analysis of different slope sections were carried out using finite element based software.

The global stability analysis of rock slope, as shown in figure 3, has not predicted any significant mass movement. However, instability is observed in potential wedges when they are analyzed on a local scale under critical loading conditions.

Fig. 2. Right bank slope comprising Quartzite and Dolomitic Limestone - Area of study

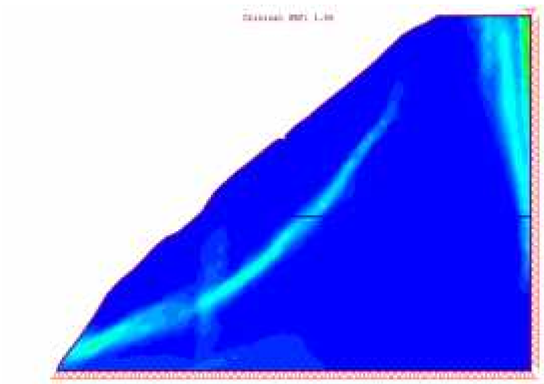

Fig. 3. Output of Global Stability analysis in Phase 2 Software

5 Support System

Structural support systems were recommended to stabilize the potentially unstable zones. After identifying the unstable wedges, the structural supports like systematic rock bolting of 8 to 10m length and spacing varying from 1.5m to 2.5m combined with 100mm thick shotcrete lining with welded wire mesh is recommended. Installation of rock bolts is governed by the field conditions such as evident formation of wedges and limitations of access to such locations. Figure 4 shows a typical unstable wedge stabilized by providing rock bolts.

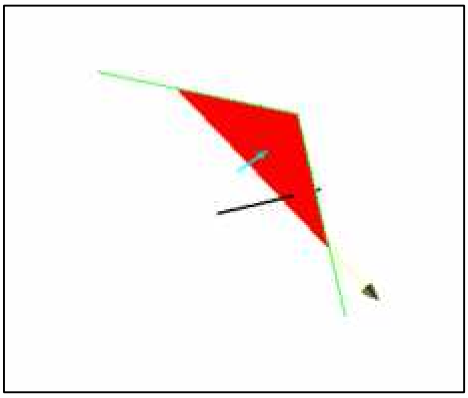

Fig. 4. Typical unstable rock wedge analyzed in SWedge software

6 Conclusion

It has been presented in this paper that geological and geotechnical characterization of rock slope is a challenging task. The challenge increases when it comes to recommend and execute the stabilization of rock slope for construction of large structures like dams.

Therefore it is imperative that the rock slopes should be characterized with great expertize considering all aspects of major structural features present in rocks. The methods available for rock slope analyses should be used wherever applicable considering the behavior of the rockmass and limitations of the method.

The rock slope support measures should be designed to come out with optimum solution in terms of safety and economy considering the objective of stabilization, the risk involved and the field conditions. A case study of rock slope stabilization at a proposed dam abutments is presented is this paper.

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